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WORLD INTELLECTUAL PROPERTY ORGANIZATION
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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 7 : H01L 51/20	A1	(11) International Publication Number: WO 00/48257 (43) International Publication Date: 17 August 2000 (17.08.00)

(21) International Application Number: PCT/GB00/00476

(22) International Filing Date: 14 February 2000 (14.02.00)

(30) Priority Data:
9903251.8 12 February 1999 (12.02.99) GB

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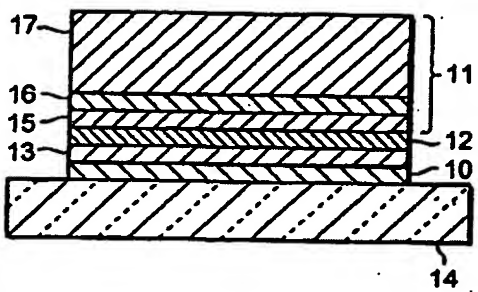
(81) Designated States: AE, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CR, CU, CZ, DE, DK, DM, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published
With international search report.

(54) Title: OPTO-ELECTRICAL DEVICES



(57) Abstract

An opto-electrical device comprising: an anode electrode (10); a cathode electrode (11); and an opto-electrically active region (12) located between the electrodes; the cathode electrode including: a first layer (15) comprising a material having a work function below 3.5 eV; a second layer (16) of a different composition from the first layer, comprising another material having a work function below 3.5 eV; the second layer being further from the opto-electrically active region than the first layer; and a third layer (17) comprising a material having a work function above 3.5 eV, the third layer being further from the opto-electrically active region than the first layer.

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OPTO-ELECTRICAL DEVICES

This invention relates to opto-electrical devices, for example devices for emitting or detecting light.

One specific class of opto-electrical devices is those that use an organic material for light emission or detection. Light-emissive organic materials are described in PCT/WO90/13148 and US 4,539,507, the contents of both of which are incorporated herein by reference. The basic structure of these devices is a light-emissive organic layer, for instance a film of a poly(p-phenylenevinylene ("PPV"), sandwiched between two electrodes. One of the electrodes (the cathode) injects negative charge carriers (electrons) and the other electrode (the anode) injects positive charge carriers (holes). The electrons and holes combine in the organic layer generating photons. In PCT/WO90/13148 the organic light-emissive material is a polymer. In US 4,539,507 the organic light-emissive material is of the class known as small molecule materials, such as (8-hydroxyquinoline)aluminium ("Alq3"). In a practical device one of the electrodes is typically transparent, to allow the photons to escape the device.

Figure 1 shows a typical cross-sectional structure of such an organic light-emissive device ("OLED"). The OLED is typically fabricated on a glass or plastic substrate 1 coated with a transparent material such as indium-tin-oxide ("ITO") to form an anode 2. Such coated substrates are commercially available. The ITO-coated substrate is covered with at least a thin film of an electroluminescent organic material 3 and a final cathode layer 4, which is typically a metal or alloy.

Some particularly attractive applications of such devices are as displays in battery-powered units such as portable computers and mobile phones. Therefore, to extend the battery life of such units, there is a particularly strong need to increase the efficiency of the light-emissive devices. One route to improving efficiency is by careful choice and design of the light-emissive material itself. Another is by

optimising the physical layout of the display. A third is by improving the conditions for charge injection into and charge recombination in the emissive layer.

To improve the conditions for charge injection into and charge recombination in the emissive layer it is known to include a charge transport layer of an organic material such as polystyrene sulphonic acid doped polyethylene dioxythiophene ("PEDOT-PSS") between one or both of the electrodes and the emissive layer. A suitably chosen charge transport layer can enhance charge injection into the emissive layer and resist reverse flow of charge carriers, which favours charge recombination. It is also known to form the electrodes from materials having work functions that aid the desired flow of charge carriers. For example, a low work function material such as calcium or lithium is preferred as the cathode. PCT/WO97/08919 discloses a cathode formed of a magnesium:lithium alloy.

According to one aspect of the present invention there is provided an opto-electrical device comprising: an anode electrode; a cathode electrode; and an opto-electrically active region located between the electrodes; the cathode electrode including: a first layer comprising a material having a work function below 3.5 eV; a second layer of a different composition from the first layer, comprising another material having a work function below 3.5 eV, the second layer being further from the opto-electrically active region than the first layer; and a third layer comprising a material having a work function above 3.5 eV, the third layer being further from the opto-electrically active region than the first layer..

According to a second aspect of the present invention there is provided a method for forming an opto-electrical device, the method comprising: depositing an anode electrode; depositing over the anode electrode a region of an opto-electrically active material; depositing over the region of opto-electrically active material a material having a work function below 3.5 eV to form a first cathode layer; depositing over the first cathode layer another material having a work function below 3.5 eV to form a second cathode layer of a different composition from the

first cathode layer; and depositing over the second cathode layer a material having a work function above 3.5 eV to form a third cathode layer.

The first layer may be adjacent to the opto-electrically active region or there may be one or more other layers (preferably electrically conductive layers) between the first layer and the opto-electrically active region. The opto-electrically active region is suitably in the form of a layer, preferably a layer of an opto-electrically active material. The opto-electrically active region is suitably active to emit light or to generate an electrical field in response to incident light. The device is preferably an electroluminescent device.

The thickness of the first layer is suitably less than 50 Å, optionally less than 30 Å, or less than 25 Å or 20 Å. The thickness of the first layer could be less than 15 Å or 10 Å. The thickness of the first layer may be in the range from 5 Å to 20 Å, possibly around 15 Å. More generally, it is preferred that the thickness of the first layer is in the range from 10 Å to 140 Å. The first layer is preferably, but not necessarily thinner than the second layer.

The thickness of the second layer is suitably less than 1000 Å, and preferably less than 500 Å. The thickness of the second layer is suitably more than 40 Å or 100 Å, and optionally more than 150 Å or 200 Å. The thickness of the second layer is preferably in the range from 40 Å to 500 Å.

The said material having a work function below 3.5 eV of which the first layer is comprised ("the first low work function material") preferably has a higher work function than the said material having a work function below 3.5 eV of which the second layer is comprised ("the second low work function material"), or could alternatively have a lower work function than it. The work functions of the materials as referred to herein are preferably their effective work functions in the device, which may be different from their bulk work functions. Thus the first low work function material preferably has an effective work function in the device of

less than 3.5eV and/or the second low work function material preferably has an effective work function in the device of less than 3.5 eV.

One of the first and second low work function materials is preferably a compound or complex of a group 1, group 2 or transition metal. That material is preferably a compound - for example a halide (e.g. a fluoride), oxide, carbide or nitride). That material is preferably a compound of a metal such as Mg, Li, Cs or Y.

The second low work function material may be a metal selected from the following list: Li, Ba, Mg, Ca, Ce, Cs, Eu, Rb, K, Sm, Y, Na, Sm, Sr, Tb or Yb; or an alloy of two or more of such metals; or an alloy of one or more of such metals together with another metal such as Al, Zr, Si, Sb, Sn, Zn, Mn, Ti, Cu, Co, W, Pb, In or Ag.

The first and second low work function materials are preferably different materials. In one preferred embodiment the first low work function material is calcium and the second low work function material is lithium fluoride. In another preferred embodiment the second low work function material is calcium and the first low work function material is lithium fluoride

The first low work function material suitably has a (effective) work function less than 3.4 eV, or less than 3.3 eV or less than 3.2 eV, or less than 3.2 eV or less than 3.1 eV or less than 3.0 eV. The second low work function material suitably has a (effective) work function less than 3.4 eV, or less than 3.3 eV or less than 3.2 eV, or less than 3.2 eV or less than 3.1 eV or less than 3.0 eV.

The first low work function material preferably does not cause significant degradation of the material of the active region when the two are in contact. The second low work function material may be a material that is capable of causing degradation of the material of the active region when the two are in contact. The first low work function material may, when in contact with the material of the active region, form an intermediate state between those of the material of the active region and those of the second layer.

The work function of the material of the third layer is preferably greater than 4.0 eV. The higher work function material is suitably a metal or an oxide. The higher work function material and/or the third layer itself preferably has an electrical conductivity greater than 10^5 (Ω.cm)$^{-1}$. The higher work function material is preferably Al, Cu, Ag, Au or Pt; or an alloy of two or more of those metals; or an alloy of one or more of those metals together with another metal; or an oxide such as tin oxide or indium-tin oxide (ITO). The thickness of the third layer is preferably in the range from 1000 Å to 10000 Å, preferably in the range from 2000 Å to 6000 Å, and most preferably around 4000 Å.

Suitably more than 50%, more than 80%, more than 90% or more then 95% of the first layer consists of the first low work function material. Preferably the first layer substantially wholly comprises the first low work function material. Most preferably the first layer consists of the first low work function material together with any impurities. Suitably more than 50%, more than 80%, more than 90% or more then 95% of the second layer consists of the second low work function material. Preferably the second layer substantially wholly comprises the second low work function material. Most preferably the second layer consists of the second low work function material together with any impurities. Suitably more than 50%, more than 80%, more than 90% or more then 95% of the third layer consists of the higher work function material. The third layer preferably substantially wholly comprises the higher work function material. Most preferably the third layer consists of the higher work function material together with any impurities.

The second layer is preferably adjacent to the first layer. The third layer is preferably adjacent to the second layer. Alternatively, the cathode may comprise further layers located between the first, second and/or third layers. The cathode is preferably inorganic, most preferably metallic.

One of the electrodes is preferably light-transmissive, and most preferably transparent. This is preferably but not necessarily the anode electrode, which could be formed of tin oxide (TO), indium-tin oxide (ITO) or gold.

The opto-electrically active region may be light-emissive or (suitably on the application of a suitable electric field across it) or may be light-sensitive (suitably generating an electric field in response to incident light). The opto-electrically active region suitably comprises a light-emissive material or a light-sensitive material. Such a light-emissive material is suitably an organic material and preferably a polymer material. The light-emissive material is preferably a semiconductive and/or conjugated polymer material. Alternatively the light-emissive material could be of other types, for example sublimed small molecule films or inorganic light-emissive material. The or each organic light-emissive material may comprise one or more individual organic materials, suitably polymers, preferably fully or partially conjugated polymers. Example materials include one or more of the following in any combination: poly(p-phenylenevinylene) ("PPV"), poly(2-methoxy-5(2'-ethyl)hexyloxyphenylene-vinylene) ("MEH-PPV"), one or more PPV-derivatives (e.g. di-alkoxy or di-alkyl derivatives), polyfluorenes and/or co-polymers incorporating polyfluorene segments, PPVs and related co-polymers, poly(2,7-(9,9-di-n-octylfluorene)-(1,4-phenylene-((4-secbutylphenyl)imino)-1,4-phenylene)) ("TFB"), poly(2,7-(9,9-di-n-octylfluorene) - (1,4-phenylene-((4-methylphenyl)imino)-1,4-phenylene-((4 - methylphenyl)imino) - 1,4-phenylene)) ("PFM"), poly(2,7 - (9,9 - di-n-octylfluorene) - (1,4-phenylene-((4-methoxyphenyl)imino)-1,4-phenylene- ((4-methoxyphenyl)imino)-1,4-phenylene)) ("PFMO"), poly (2,7-(9,9-di-n-octylfluorene) ("F8") or (2,7-(9,9-di-n-octylfluorene)-3,6-Benzothiadiazole) ("F8BT"). Alternative materials include small molecule materials such as Alq3.

There may be one or more other layers in the device. There may be one or more charge transport layers (preferably of more or more organic materials) between the active region and one or other of the electrodes. The or each charge transport layer may suitably comprise one or more polymers such as polystyrene sulphonic

acid doped polyethylene dioxythiophene ("PEDOT-PSS"), poly(2,7-(9,9-di-n-octylfluorene)-(1,4-phenylene-(4-imino(benzoic acid))-1,4-phenylene-(4-imino(benzoic acid))-1,4-phenylene)) ("BFA"), polyaniline and PPV.

The present invention will now be described by way of example with reference to the accompanying drawings, in which:

figure 2 is a cross-section of a light-emissive device;

figures 3 to 4 show data on the performance of several light-emissive devices; and

figures 5 and 6 show experimental data for a set of devices having cathodes of different compositions;

figure 7 shows experimental data for a set of devices having cathodes of different configurations; and

figures 8 and 9 show experimental data for devices having cathode layers of different thicknesses.

The illustrated thicknesses of the layers in figure 2 are not to scale.

The device of figure 2 comprises an anode electrode 10 and a cathode electrode 11. Located between the electrode layers is an active layer 12 of light-emissive material. A charge transport layer 13 of PEDOT:PSS is located between the anode electrode 10 and the light-emissive layer 12. The device is formed on a glass substrate 14.

The metallic cathode 11 comprises three layers. Next to the emissive layer 12 is a first layer 15, of calcium. Over that is a second layer 16, of lithium. Over that is a third layer 17, of aluminium. As will be described below, this structure has been found to provide a significant increase in device efficiency.

To form the device of figure 2 a transparent layer of ITO to form the anode electrode 10 may first be deposited on a sheet of glass 14. The glass sheet could be a sheet of sodalime or borosilicate glass of a thickness of, for instance, 1mm. The thickness of the ITO coating is suitably around 100 to 150nm and the ITO

suitably has a sheet resistance of between 10 and 30 $\Omega/\square$. ITO-coated glass substrates of this type are commercially available. As an alternative to glass, the sheet 14 could be formed of perspex. As an alternative to ITO, gold or TO could be used as the anode.

Over the ITO anode is deposited a hole transport or injecting layer 13. The hole transport layer is formed from a solution containing PEDOT:PSS with a ratio of PEDOT to PSS of around 1 to 5.5. The thickness of the hole transport layer is suitably around 500 Å. The hole transport layer is spin-coated from solution and then baked at around 200°C for 1 hour in a nitrogen environment.

Then the electroluminescent layer 15 is deposited. In this example, the electroluminescent layer is formed of 20% TFB in 5BTF8. The term 5BTF8 refers to poly (2,7-(9,9-di-*n*-octylfluorene) ("F8") doped with 5% poly-(2,7-(9,9-di-*n*-octylfluorene)-3,6-benzothiadiazole) ("F8BT"). the term TFB refers to poly(2,7-(9,9-di-n-octylfluorene)-(1,4-phenylene-((4-secbutylphenyl)imino)-1,4-phenylene)). This mixture is coated over the hole transport layer by spin-coating typically to a thickness of around 750 Å. Other materials such as PPV could be used for the emissive layer. The emissive layer could be formed by other routes such as blade or meniscus coating and could be deposited in precursor form if desired.

The cathode is then deposited. The three distinct layers of the cathode are deposited by successive thermal evaporation steps *in vacuo* at a base pressure of less than 10^{-8} mbar. Preferably the vacuum is not broken between the successive steps, to reduce the possibility of contamination of the interfaces between the layers. One alternative to thermal evaporation is sputtering, but this is less preferred for at least the deposition of the layer 15 adjacent to the emissive layer since it may cause damage to the emissive layer 12. In the first thermal evaporation step the layer 15 is deposited. The layer 15 is of calcium and has a thickness of approximately 5 to 25 Å, preferably around 15 Å. In the second thermal evaporation step the layer 16 is deposited. The layer 16 is of lithium and has a thickness of around 100 to 500 Å. In the third thermal evaporation step the

layer 17 is deposited. The layer 17 is of aluminium and has a thickness of around 4000 Å.

Finally, contacts are attached to the layers 10 and 17 and, although the aluminium layer 16 may act to some extent as an encapsulant, the device is preferably sealed in epoxy resin for environmental protection.

In use, when a suitable voltage is applied between the anode and the cathode the light-emissive layer is stimulated to emit light. This passes to a viewer through the transparent anode and the glass cover sheet.

The applicant has found that a device of this type has significantly increased efficiency. Figures 3 to 4 show data for the performance of devices of a similar device to that of figure 2 (devices E to H) and two comparative device designs (devices A to D and devices J to P).

The common structures of the devices were as follows:

- Substrate: glass
- Anode: ITO
- Charge transport layer: 1:5.5 PEDOT:PSS; thickness 500 Å
- Emissive layer: 4:1 5BTF8:TFB; thickness 750 Å

The cathodes of the devices were as follows:

Devices A to D:

- calcium layer of thickness 500 Å adjacent to emissive layer; and
- capping layer of aluminium of thickness 4000 Å.

Devices E to H:

- lithium layer of thickness 500 Å adjacent to emissive layer; then
- calcium layer of thickness 1000 Å; and
- capping layer of aluminium of thickness 4000 Å.

Devices J to P:

- lithium layer of thickness 25 Å adjacent to emissive layer; and

- capping layer of aluminium of thickness 4000 Å.

Figure 3 shows the peak measured efficiencies of the devices in Lm/W and Cd/A. Figure 4 shows the drive voltages for the devices at brightnesses of 0.01, 100 and 1000 Cd/m^2. Figure 3 shows that the peak efficiency of devices E to H is markedly greater than those of the other devices. Figure 4 shows that devices E to H do not suffer any significant increase in drive voltage, and have significantly lower drive voltages than devices J to P.

Figures 5 to 9 show data for further similar devices. Figure 5 shows experimental data for devices comprising an ITO anode, an 80nm layer of PEDOT:PSS, a 63nm layer of a blue emissive material (spin-coated in a glovebox) and a cathode formed of a first layer next to the emissive layer of a composition as indicated against the respective plot, a second 10nm layer of Ca and a final layer of Al. Figure 6 shows experimental data for devices comprising an ITO anode, an 80nm layer of PEDOT:PSS, a 70nm layer of a green emissive material (F8:TFB:F8BT spin-coated in a glovebox) and a cathode formed of a first layer next to the emissive layer of a composition as indicated against the respective plot, a second 10nm layer of Ca and a final layer of Al. The experimental data are: electroluminescence spectra, luminous efficiency against voltage, current density against voltage, brightness against voltage and brightness against time. The efficiency data are summarised as follows:

Material of first cathode layer	Blue: maximum Lm/W	Green: maximum Lm/W
MgF_2	0.30	8.5
MgI_2	0.01	0.12
LiF	2.0	15
LiCl	0.18	10
LiBr	0.05	12
LiI	0.35	13
CsCl	0.60	0.9

CsBr	0.75	4.5
CsI	0.80	8.0
YF	1.25	14
CaAl	0.73	16

The EL spectra of the blue emitters were only slightly dependant on the cathode materials used, those with higher current densities showing the typical aggregate feature. Green spectra were relatively independent of the cathode materials used. The device performance appeared to be principally dependant on the metal constituent of the first cathode layer. The Mg-based devices had the worst performance for both emissive polymers, with relatively lo efficiencies and currents. Cs-based devices had intermediate performance. LiF gave the highest performing devices. Other Li halides had relatively poor performance for blue emission and variable efficiency for green.

Figure 7 shows efficiency data for similar devices having ITO anodes, a PEDOT:PSS layer, an emissive layer capable of emitting blue, green or red light (as indicated on the respective plot) and electrodes of:

(a) a Ca layer adjacent to the emitter and an upper layer of Al;

(b) a LiF layer (6nm thick) adjacent to the emitter, then a layer of Ca (10nm thick) and an upper layer of Al;

(c) a Ca layer (5nm thick) adjacent to the emitter, then a layer of LiF (6nm thick) and an upper layer of Al.

Figure 8 shows efficiency data as a plot of maximum Lm/W for similar blue, green and red devices having a range of thicknesses for the LiF layer in the Ca/LiF/Al configuration. Figure 9 shows efficiency data as a plot of maximum Lm/W for devices having a range of thicknesses for the LiF layer in the LiF/Ca/Al configuration.

The applicant has also obtained advantageous results by replacing the Ca layer in such devices with a similar layer of Yb or Ba. Other materials such as Sm, Y and Mg would be expected to yield similar results.

Most of the above devices include in their cathodes a layer of a group 1 or group 2 metal halide, such as LiF. Other group 1 and 2 metal compounds and complexes, such as LiO have been investigated by the applicant and found to give advantageous results. Transition metal halides, compounds and complexes, such as YF (see above) may also give advantageous results. Organic complexes of group 1, group 2 or transition metals may also give advantageous results. These materials include materials that may potentially operate by providing a barrier effect (e.g. LiO) or by another effect due to their low effective work function in this situation (e.g. LiF).

It is believed that, when the layer 15 of the cathode that is adjacent to the emissive layer 12 is sufficiently thin that the properties of the overlying cathode layer 16 can influence charge injection from the cathode into the emissive layer, there is an opportunity to select materials for the layers 15 and 16 such that by a combination of their properties the performance of the device can be enhanced. Possible mechanisms for this enhancement are believed to include: (a) prevention by the layer 15 of adverse interactions between organic layer(s) of the device (e.g. layer 15) and the material of the layer 16, whilst retaining at least some of the injection properties of the material of the layer 16; and (b) the formation by the layer 15 (e.g. with organic layer(s) such as layer 15) of intermediate states that aid electron injection from the layer 16. The layer 15 should be sufficiently thin to allow the effect to occur but sufficiently thick that it can be deposited reproducibly and uniformly (without excessive defects). To exploit possible mechanism (a) the layer 16 could be formed from a material that is more reactive than that of layer 15, but has a lower work function. It should also be noted that highly advantageous performance is also obtained when a layer of a suitable material (e.g. LiF) is spaced slightly from the emissive material, as in the Ca/LiF/Al devices of figures 7 and 8. In general, possible mechanisms include surface induced dipoles, modified work functions, charge transfer formation of chemically stable compounds and dissociation of the compound layer of the cathode to form a doped injection layer.

It should be noted that in assessing experimentally devices of the types described above the upper layer of the cathode (e.g. of Al) provides important protective effects. Instead of Al other suitable materials include Ag or ITO, which have the advantages of being able to provide a transparent layer whereby the whole cathode may be transparent or at least translucent. This is advantageous for devices that are intended to emit through the cathode.

A device of the type described above may form a pixel of a multi-pixel display device.

The devices described above may be varied in many ways within the scope of the present invention.. For example, the capping layer 17 could be omitted; the layers could be formed of different materials; additional layers could be present, in the cathode or elsewhere in the device; or one or more additional charge transport layers could be provided between the light-emissive layer and either or both of the electrodes to assist charge transport between the respective electrode and the light-emissive layer and/or to resist charge transport in the opposite direction. The emissive material could be of the class of sublimed molecular films, as described for example in "Organic Electroluminescent Diodes", C. W. Tang and S. A. VanSlyke, Appl. Phys. Lett. 51, 913-915 (1987). The locations of the electrodes could be reversed so that the cathode is located at the front of the display (closest to the viewer) and the anode is at the back.

The same principles may be applied to devices for the detection rather than the generation of light. By replacing (if necessary) the light-emissive material with a material that is capable of generating an electrical field in response to light the improved characteristics of the improved electrodes as described above may be used to enhance detection voltages and/or efficiency.

The applicant draws attention to the fact that the present invention may include any inventive feature or combination of features disclosed herein either implicitly or explicitly or any generalisation thereof, without limitation to the scope of any of the

present claims. In view of the foregoing description it will be evident to a person skilled in the art that various modifications may be made within the scope of the invention.

CLAIMS

1. An opto-electrical device comprising:

an anode electrode;

a cathode electrode; and

an opto-electrically active region located between the electrodes;

the cathode electrode including:

a first layer comprising a material having a work function below 3.5 eV;

a second layer of a different composition from the first layer, comprising another material having a work function below 3.5 eV, the second layer being further from the opto-electrically active region than the first layer; and

a third layer comprising a material having a work function above 3.5 eV, the third layer being further from the opto-electrically active region than the first layer.

2. An opto-electrical device as claimed in claim 1, wherein one of the first and second layers comprises a compound of a group 1 or group 2 or transition metal.

3. An opto-electrical device as claimed in claim 2, wherein the compound is a halide.

4. An opto-electrical device as claimed in any preceding claim, wherein the compound is a fluoride.

5. An opti-electrical device as claimed in any of claims 2 to 4, wherein the metal is a group 1 or 2 metal.

6. An opto-electrical device as claimed in claim 5, wherein the metal is lithium.

7. An opto-electrical device as claimed in any of claims 2 to 6, wherein the said one of the layers is the first layer.

8. An opto-electrical device as claimed in any of claims 2 to 6, wherein the said one of the layers is the second layer.

9. An opto-electrical device as claimed in any of claims 2 to 8, wherein the other of the first and second layers comprises a metal.

10. An opto-electrical device as claimed in claim 9, wherein the other of the first and second layers comprises a metal selected from the group comprising: Li, Ba, Mg, Ca, Ce, Cs, Eu, Rb, K, Y, Sm, Na, Sm, Sr, Tb or Yb.

11. An opto-electrical device as claimed in any preceding claim, wherein the second layer is thicker than the first layer.

12. An opto-electrical device as claimed in any preceding claim, wherein the thickness of the second layer is greater than 100 Å.

13. An opto-electrical device as claimed in any preceding claim, wherein the said material having a work function below 3.5 eV of which the first layer is comprised has a higher work function than the said material having a work function below 3.5 eV of which the second layer is comprised.

14. An opto-electrical device as claimed in any preceding claim, wherein the thickness of the third layer is greater than 1000 Å.

15. An opto-electrical device as claimed in any preceding claim, wherein the said material having a work function above 3.5eV has an electrical conductivity greater than 10^5 $(\Omega.cm)^{-1}$.

16. An opto-electrical device as claimed in any preceding claim, wherein the said material having a work function above 3.5eV is aluminium, gold or indium-tin oxide

17. An opto-electrical device as claimed in any preceding claim, wherein the cathode is transparent.

18. An opto-electrical device as claimed in any preceding claim, wherein the opto-electrically active region is light-emissive.

19. An opto-electrical device as claimed in any preceding claim, wherein the opto-electrically active region comprises a light-emissive organic material.

20. An opto-electrical device as claimed in claim 19, wherein the light-emissive organic material is a polymer material.

21. An opto-electrical device as claimed in claim 20, wherein the light-emissive organic material is a conjugated polymer material.

22. An opto-electrical device as claimed in any of claims 19 to 21, comprising a charge transport layer between the light-emissive organic material and one of the electrodes.

23. A method for forming an opto-electrical device, the method comprising:

depositing an anode electrode;

depositing over the anode electrode a region of an opto-electrically active material;

depositing over the region of opto-electrically active material a material having a work function below 3.5 eV to form a first cathode layer;

depositing over the first cathode layer another material having a work function below 3.5 eV to form a second cathode layer of a different composition from the first cathode layer; and

depositing over the second cathode layer a material having a work function above 3.5 eV to form a third cathode layer.

24. An opto-electrical device substantially as herein described with reference to figures 2 to 9 of the accompanying drawings.

25. A method for forming an opto-electrical device substantially as herein described with reference to figures 2 to 9 of the accompanying drawings.

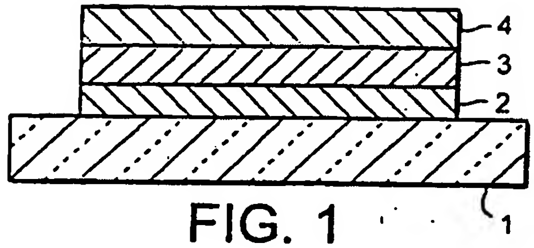


FIG. 1

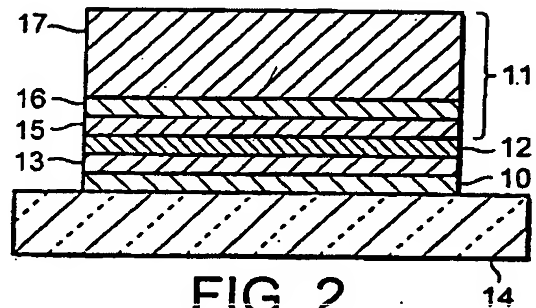


FIG. 2

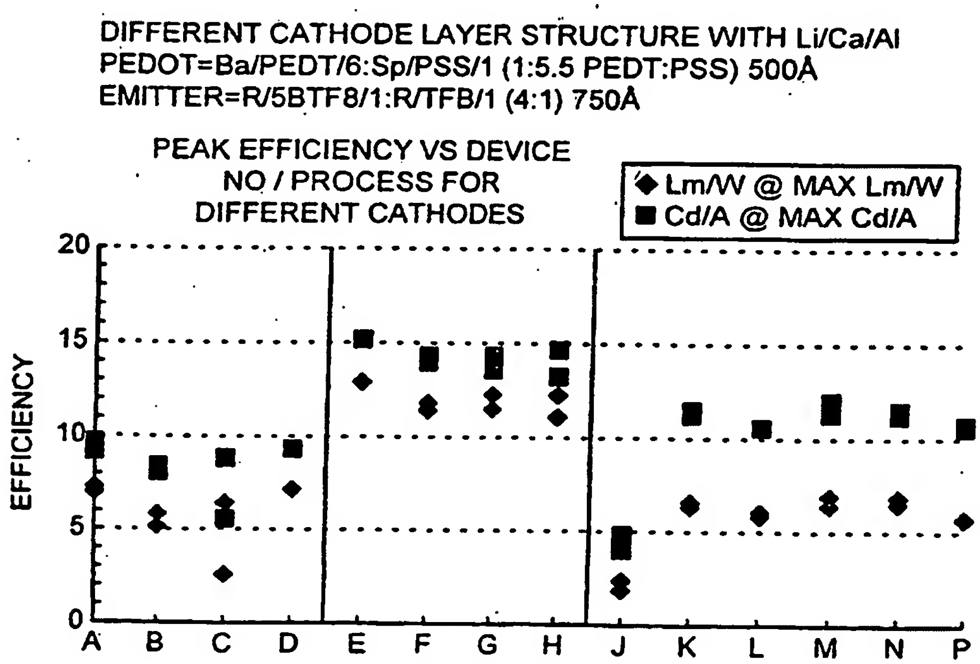


FIG. 3

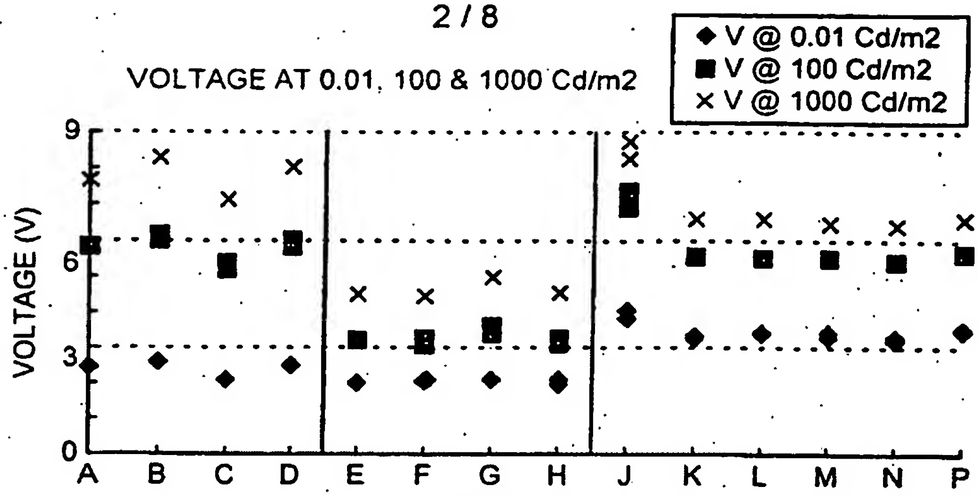

VOLTAGE AT 0.01, 100 & 1000 Cd/m2
V @ 0.01 Cd/m2
V @ 100 Cd/m2
V @ 1000 Cd/m2
VOLTAGE (V)
0
3
6
9
A
B
C
D
E
F
G
H
J
K
L
M
N
P

FIG. 4

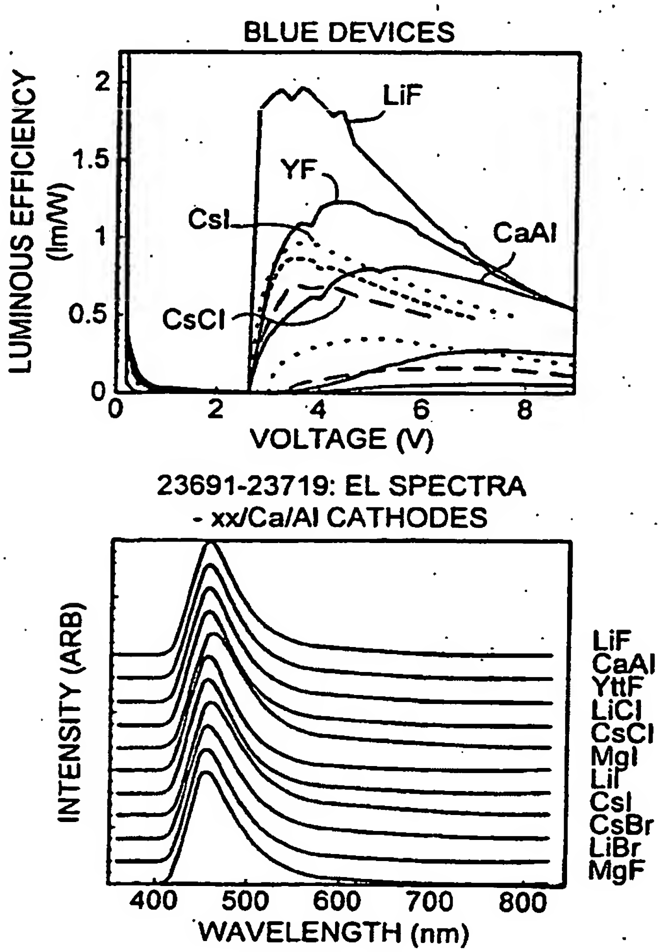
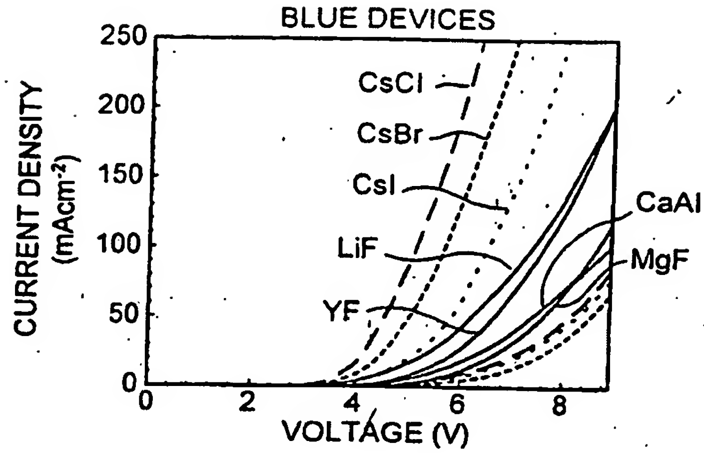
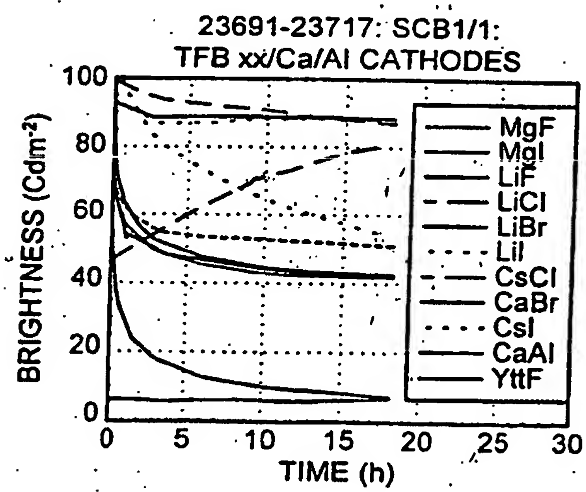

BLUE DEVICES
LUMINOUS EFFICIENCY (lm/W)
VOLTAGE (V)
LiF
YF
CsI
CaAl
CsCl
23691-23719: EL SPECTRA
- xx/Ca/Al CATHODES
INTENSITY (ARB)
WAVELENGTH (nm)
400
500
600
700
800
LiF
CaAl
YttF
LiCl
CsCl
MgI
LiI
CsI
CsBr
LiBr
MgF

FIG. 5


BLUE DEVICES
CURRENT DENSITY (mAcm⁻²)
VOLTAGE (V)
250
200
150
100
50
0
0
2
4
6
8
CsCl
CsBr
CsI
LiF
YF
CaAl
MgF


23691-23717: SCB1/1:
TFB xx/Ca/Al CATHODES
BRIGHTNESS (Cdm⁻²)
TIME (h)
100
80
60
40
20
0
0
5
10
15
20
25
30
MgF
MgI
LiF
LiCl
LiBr
LiI
CsCl
CaBr
CsI
CaAl
YttF

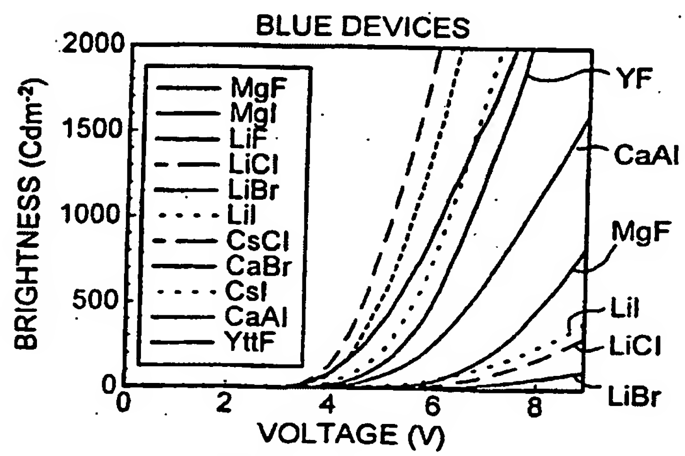

BLUE DEVICES
BRIGHTNESS (Cdm⁻²)
VOLTAGE (V)
2000
1500
1000
500
0
0
2
4
6
8
MgF
MgI
LiF
LiCl
LiBr
LiI
CsCl
CaBr
CsI
CaAl
YttF
YF
CaAl
MgF
LiI
LiCl
LiBr

FIG. 5CONT'D

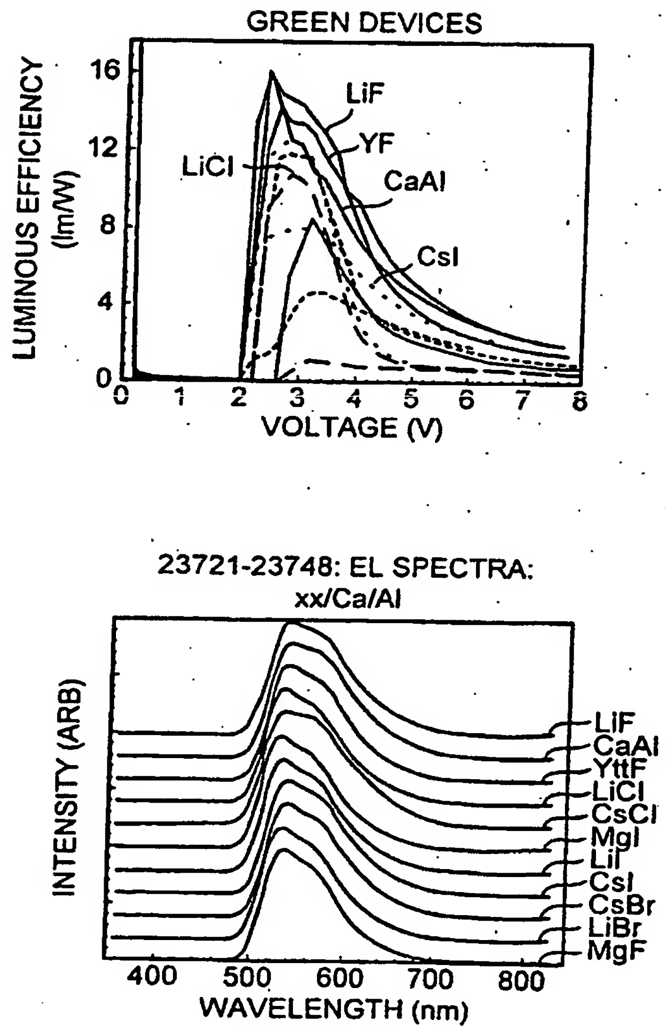

GREEN DEVICES
LUMINOUS EFFICIENCY (lm/W)
16
12
8
4
0
0 1 2 3 4 5 6 7 8
VOLTAGE (V)
LiF
YF
LiCl
CaAl
CsI
23721-23748: EL SPECTRA:
xx/Ca/Al
INTENSITY (ARB)
400 500 600 700 800
WAVELENGTH (nm)
LiF
CaAl
YttF
LiCl
CsCl
MgI
LiI
CsI
CsBr
LiBr
MgF

FIG. 6

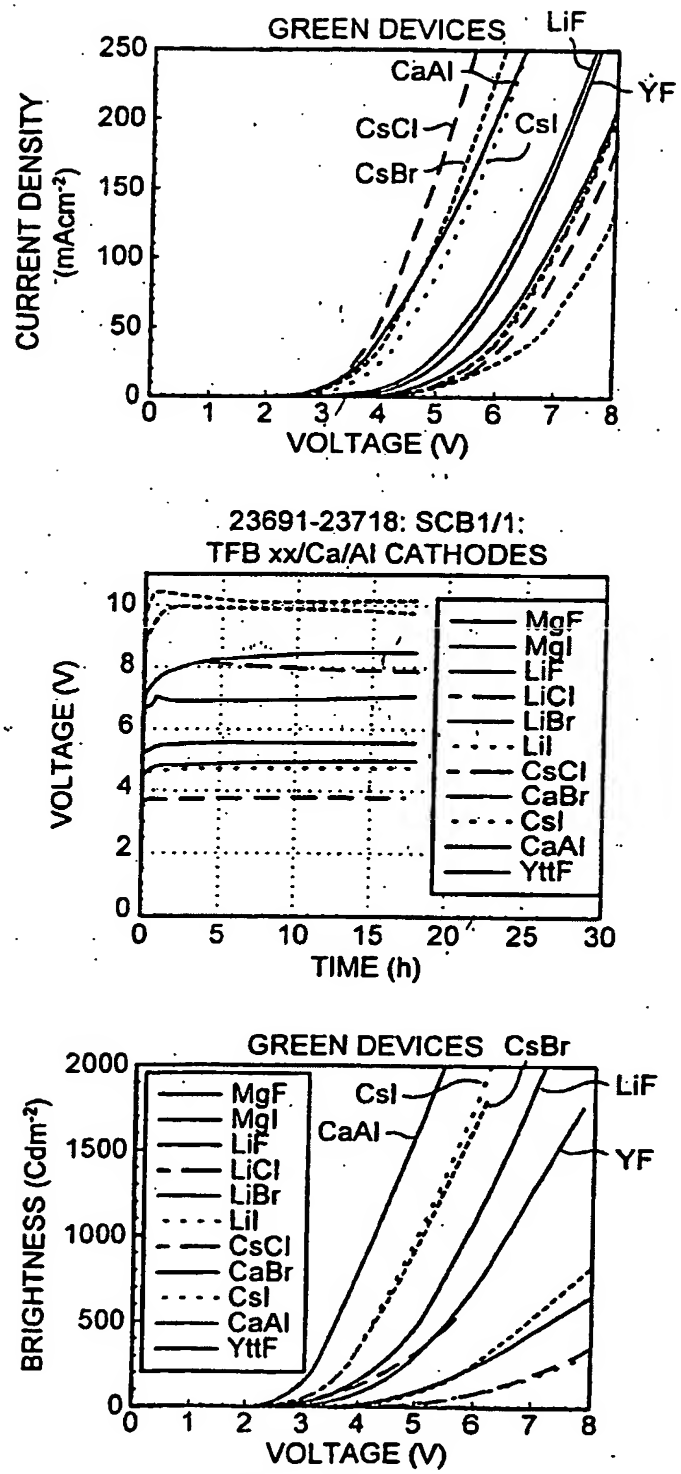

GREEN DEVICES
LiF
CaAl
YF
CsCl
CsI
CsBr
CURRENT DENSITY (mAcm^{-2})
250
200
150
100
50
0
0 1 2 3 4 5 6 7 8
VOLTAGE (V)
23691-23718: SCB1/1:
TFB xx/Ca/Al CATHODES
VOLTAGE (V)
10
8
6
4
2
0
0 5 10 15 20 25 30
TIME (h)
MgF
MgI
LiF
LiCl
LiBr
LiI
CsCl
CaBr
CsI
CaAl
YttF
GREEN DEVICES
CsBr
LiF
CsI
CaAl
YF
BRIGHTNESS (Cdm^{-2})
2000
1500
1000
500
0
MgF
MgI
LiF
LiCl
LiBr
LiI
CsCl
CaBr
CsI
CaAl
YttF
0 1 2 3 4 5 6 7 8
VOLTAGE (V)

FIG. 6CONT'D

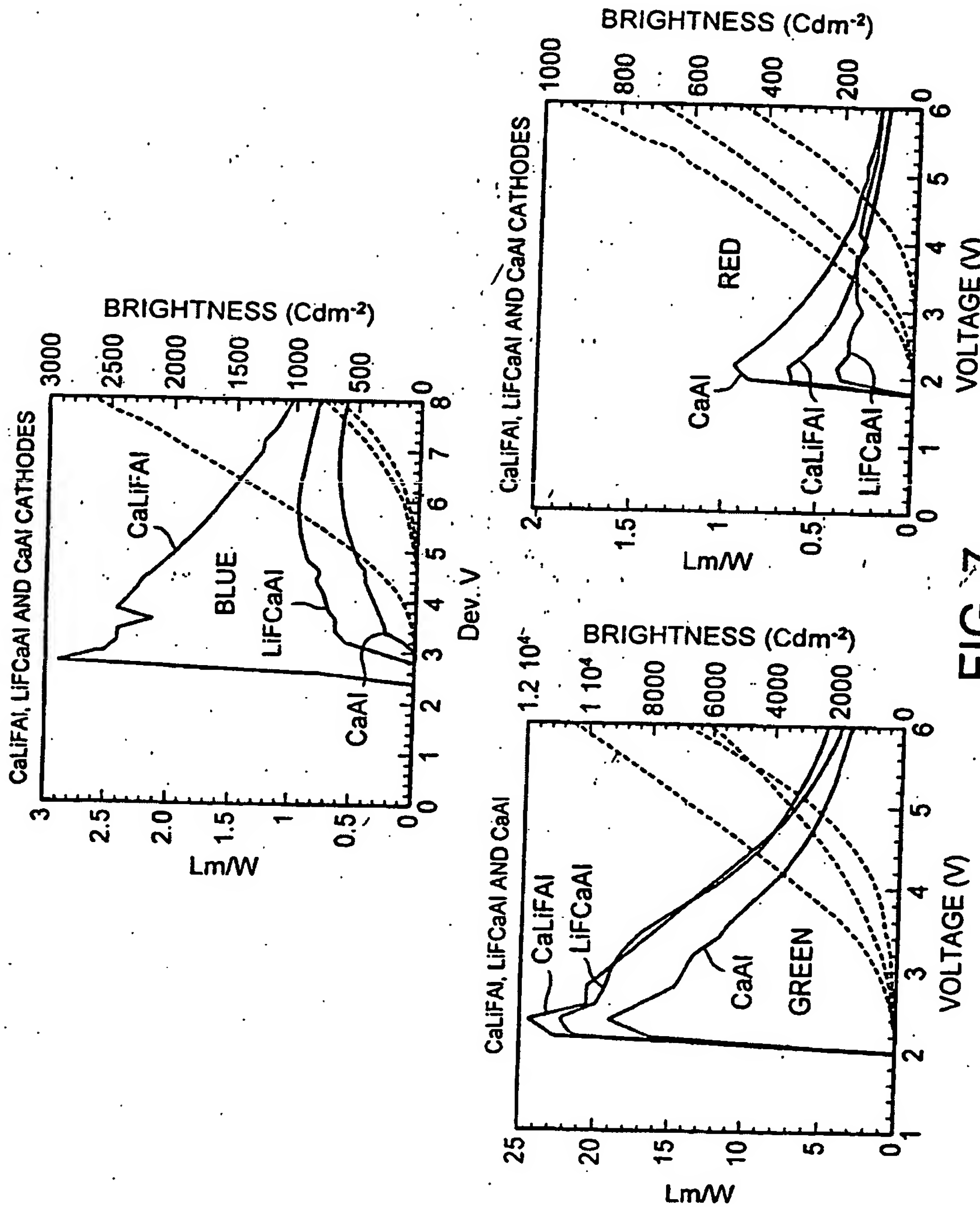

CaLiFAl, LiFCaAl AND CaAl CATHODES
BRIGHTNESS (Cdm-2)
BLUE
CaLiFAl
LiFCaAl
CaAl
Lm/W
Dev. V
CaLiFAl, LiFCaAl AND CaAl CATHODES
RED
CaAl
CaLiFAl
LiFCaAl
VOLTAGE (V)
CaLiFAl, LiFCaAl AND CaAl
GREEN
CaLiFAl
LiFCaAl
CaAl
VOLTAGE (V)

FIG. 7

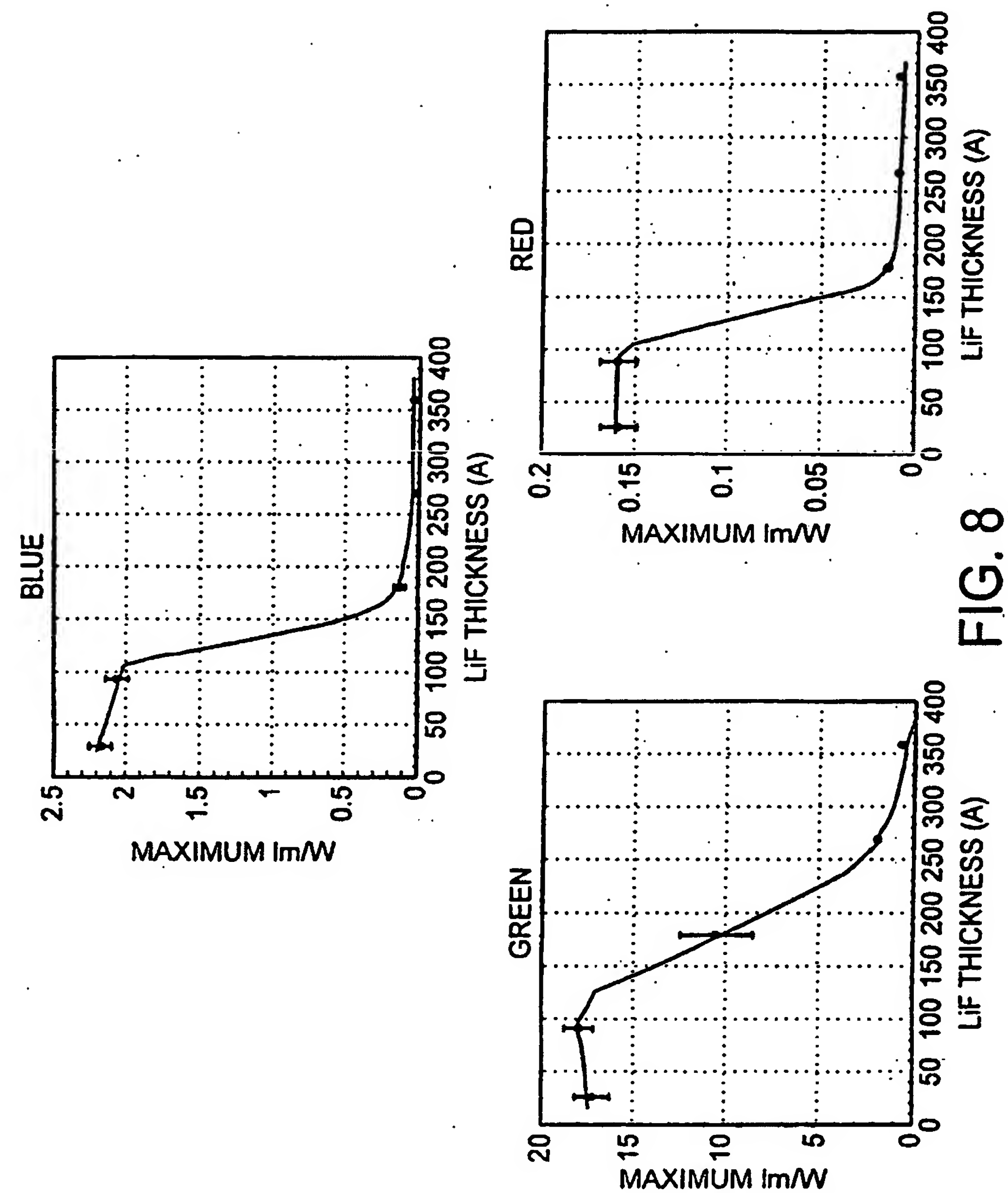

BLUE
MAXIMUM lm/W
LiF THICKNESS (A)
RED
MAXIMUM lm/W
LiF THICKNESS (A)
GREEN
MAXIMUM lm/W
LiF THICKNESS (A)

FIG. 8

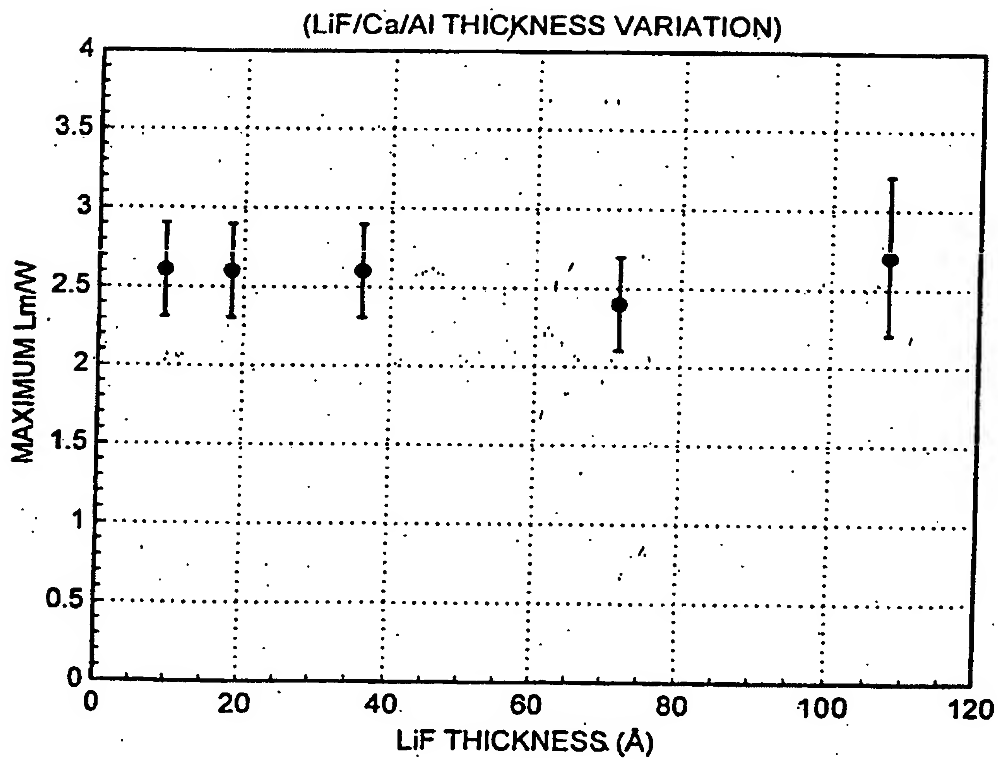

(LiF/Ca/Al THICKNESS VARIATION)
MAXIMUM Lm/W
0
0.5
1
1.5
2
2.5
3
3.5
4
0
20
40
60
80
100
120
LiF THICKNESS (Å)

FIG. 9

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 00/00476

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H01L51/20

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H01L H05B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 869 701 A (MITSUBISHI CHEM CORP) 7 October 1998 (1998-10-07) column 9, line 43 -column 12, line 47; claim 2	1-5,7, 9-16, 18-25
A		6
Y	EP 0 866 644 A (FUJI PHOTO FILM CO LTD) 23 September 1998 (1998-09-23) page 6, line 46-53	1-7, 9-11, 13-25
Y	WO 98 10473 A (DEVINE PETER ;PICHLER KARL (GB); CAMBRIDGE DISPLAY TECH (GB)) 12 March 1998 (1998-03-12) page 7, line 30 -page 10, line 25	1-7, 9-11, 13-25

-/--

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier document but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
"&" document member of the same patent family

Date of the actual completion of the international search: 30 March 2000

Date of mailing of the international search report: 10/04/2000

Name and mailing address of the ISA
European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,
Fax: (+31-70) 340-3016

Authorized officer
De Laere, A

1

Form PCT/ISA/210 (second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 00/00476

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	PATENT ABSTRACTS OF JAPAN vol. 1998, no. 05, 30 April 1998 (1998-04-30) & JP 10 020819 A (CASIO COMPUT CO LTD), 23 January 1998 (1998-01-23) abstract	1,2,7,9, 10,15, 16,18, 24,25
A	US 5 739 545 A (HAIGHT RICHARD ALAN ET AL) 14 April 1998 (1998-04-14) figure 3	1,10-12, 15-25

1

Form PCT/ISA/210 (continuation of second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

Information on patent family members

Intern   al Application No
PCT/GB 00/00476

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 0869701 A	07-10-1998	JP 11026167 A	29-01-1999
EP 0866644 A	23-09-1998	JP 10321369 A	04-12-1998
WO 9810473 A	12-03-1998	CN 1228911 A	15-09-1999
		EP 0925709 A	30-06-1999
		EP 0946993 A	06-10-1999
		WO 9810621 A	12-03-1998
		GB 2333181 A	14-07-1999
		GB 2332094 A	09-06-1999
JP 10020819 A	23-01-1998	NONE	
US 5739545 A	14-04-1998	EP 0856896 A	05-08-1998
		JP 10223377 A	21-08-1998

OIPE TAP40
MAY 3 1 2006
PATENT & TRADEMARK OFFICE

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re application of
Hiroshi OGAWA — Attorney Docket No. 1982-0149P
Application. No.: 09/560,819
Confirmation No.: 5103 — Group Art Unit: 2879
Filed: April 28, 2000 — Examiner: Sikha Roy
For: RADIATION IMAGE CONVERSION PANEL

DECLARATION UNDER 37 C.F.R. § 1.132

Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Sir:

I, Hiroshi OGAWA, hereby declare and state that:

I am a citizen of Japan;

I was conferred a Bachelor of Science degree from Chiba University, Faculty of Engineering, Department of Synthetic Chemistry in March, 1972;

I joined Fuji Photo Film Co., Ltd., in April, 1972, and since then I have been working in the company and was involved in development of magnetic tapes to December 1995. I was involved in improvement of magnetic recording layer of Advanced Photo System film from December 1995 to April 1998. Further, I was involved in development of Imaging Plates from April 1998 to May 2002. I am a part of the technical staff for producing Image Plates since May 2002;

I am an inventor of the invention described and claimed in the above-identified application;

I am familiar with the prosecution of the above-identified application; and

the experimentation set forth below was conducted by me or under my direct supervision.

EXPERIMENTATION

Three radiation image conversion panels are prepared by using a similar method as described in Example 1 of the present specification.
For preparing an upper-layer phosphor sheet, phosphor used has a grain size of 8 μ m, and 60 parts of a binder is used.
For preparing a lower-layer phosphor sheet, phosphor used has a grain size of 80 μ m, and 50 parts of binder is used.
A reflective layer, a lower-layer sheet and an upper layer sheet are dried separately, and are subjected to thermo-compression bonding, the resultant being a bonded sheet. The thermo-compression bonding is conducted by using a calendar roll. The protective layer of Example 1 is applied on the bonded sheet, and the edge covering liquid of Example 1 is applied on the bonded sheet and dried to obtain a radiation image conversion panel.
Thickness of an upper-layer sheet and that of a lower-layer sheet is listed in the following table. Thickness of a reflective layer is 20 μ m.

Three radiation image conversion panels for comparative examples are prepared by using the same materials as described above but by using a different process.
A bonded sheet is prepared by coating and drying a lower-layer sheet solution on a reflective layer, and then coating and drying an upper-layer solution on the lower-layer sheet, step by step. The protective layer of Example 1 is applied on the bonded sheet, and the edge covering liquid of Example 1 is applied on the bonded sheet and dried to obtain a radiation image conversion panel.
Thickness of an upper-layer sheet and that of a lower-layer sheet is listed in the following table. Thickness of a reflective layer is 20 μ m.

The image qualities of images obtained from the radiation image conversion panels of examples and comparative examples are

evaluated by using the methods described in Example of the present specification. And sharpness is measured by modulation transfer function (MTF) (Space frequency: 2 cycle/mm) of an image obtained.

The measurement of MTF is carried out as follows. An aluminum filter having a thickness of 21mm is placed directly below the molybdenum tube. A tungsten piece of 10 cm square (thickness of 1mm, the four edges thereof having been cut such that the angle is close to 90° as much as possible) is prepared. X ray irradiation is carried out while the tungsten piece is attached firmly to the surface of the radiation image conversion panel. At the time of photography, the tungsten piece is placed so as to be inclined at a 2° angle with respect to the edges of the panel. The irradiation conditions are 3mR, 70kVp, 20mA, and 630m sec. Then, the panel is scanned to obtain a digital X ray image. The edges of the tungsten piece are detected from the image. ESF (Edge Spread Function) is obtained from the density distribution of the edges, and the ESF is differentiated to obtain LSF (Line Spread Function). By Fourier transformation of the LSF, an MTF at 2cycle/mm is obtained. The objective MTF is obtained as an average of the data of four edges.

The results are shown in the following table.

Thickness (μ m)		Light emission quantity (%)		Graininess noise (x 10^{-2})		Sharpness	
Upper-layer phosphor sheet	Lower-layer phosphor sheet	Example	Comp. example	Example	Comp. example	Example	Comp. example
180	100	100	93	0.26	0.32	0.36	0.33
140	140	100	94	0.27	0.30	0.36	0.34
100	180	102	96	0.28	0.29	0.37	0.35

As can be seen from the data in the above table, it is apparent that

the present invention provides radiation image conversion panels with higher light emission quantity, lower graininess noise and higher sharpness.

Thus, I conclude that the present invention provides unexpectedly superior results.

I declare further that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

Date: 18, May, 2006

Hiroshi Ogawa

Hiroshi OGAWA